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THE ADDED EFFECTS OF RADIANT HEAT ON PHYSIOLOGICAL
STRAINS PRODUCED IN MAN WORKING IN
HOT-DRY ENVIRONMENTS

By

ROBERT L. GLAFKA

B.A. Coe College, 1965

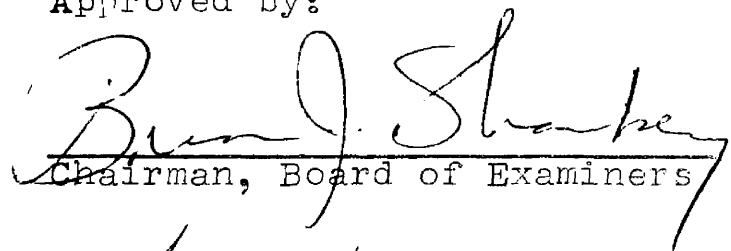
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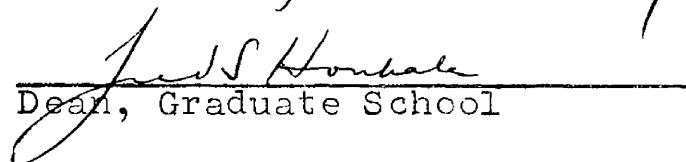
Master of Science

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R.L.G.

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CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

I. Introduction

A tremendous amount of research has been completed in recent years concerning the effects of heat stress upon the work capacity of man. Related concerns have been acclimatization (both natural and artificial), hot-wet temperature effects, and hot-dry temperature effects. While this work has been of considerable importance, a deficiency is noted; that is, the neglect of consideration of radiant heat and its effect on working capacity. This study considered the added effects radiant heat would have at various ambient temperatures with low humidity on the physiological strains produced in a man working at a moderate rate. Related to this concern was a review of heat indexes for determining which might be most applicable to field use by the United States Forest Service.

A variety of findings are available as to the physiological responses to expect and their causes at various work loads in various ambient temperatures and humidities. Iampietro and Adams (12) state that elevated body temperatures depend on the level of work performed and are generally uninfluenced by ambient temperature. In their

study, Saltin and Hermansen (19) concluded that body core temperature and probably the temperature of the working muscle is set according to the relative work load of the individual and not to the absolute work load performed. However, Edholm, Adam, and Fox (9) found a rise in body temperature during work in heat until some acclimatization took place, at which time the body temperature returned to the same levels as found during work in cool temperatures. Consolazio et al. (5) found that the metabolic rate of a fixed physical activity is increased in the heat and that this increase is not due to acclimatization or training. Similarly, Durnin and associates (8) found a small but significant increase in energy metabolism when environmental temperature was increased, even for acclimatized subjects. Findings in regard to heart rate and cardiac output have been quite uniform. Brouha et al. (4) and Kraning, Belding and Hertig (15) found significant increases in cardiac output, heart rate, and cardiac cost for subjects working in hot as compared to cool conditions. Edholm, Adam, and Fox (9) found pulse rate was always above the level observed in ambient conditions for work in the heat, even for acclimatized subjects. Williams et al. (21) stated that in heat the major change in hemodynamics was an increase in heart rate with an associated fall in stroke volume. Also, "excess" lactate occurred at significantly

lower levels of work in heat than in comfortable conditions so that working muscles were relatively more anoxic in heat at submaximal work.

Despite this wide interest in the problem of work in hot environments, little has been said concerning the increase or lack of increase in physiological demands as a result of radiant heat being added to ambient heat.

II. The Problem

Statement of the Problem

This work was done in cooperation with the Equipment Development Center of the United States Forest Service, Missoula, Montana. A need has been recognized for considering the additive effects radiant heat might have on the physiological strains produced in man at various levels of ambient temperature and low humidity while performing a moderate work task. The need has also been recognized that tests should be made on heat indexes for possible use by Forest Service officials in circumstances where heat and radiant heat are factors. The specific circumstance of concern is fire line duty.

Purpose of the Study

The purpose of this study was to determine specific and differential effects of hot-dry and radiant heat on physiological strains produced during submaximal work, thus

decreasing man's work capacity; to relate physiological responses and diminished work capacity to selected heat stress indexes; to form specific suggestions regarding use of an index with possible necessary changes by the United States Forest Service; and to promote an interest for further research in the area of the stressful working conditions which can be found in a number of occupations.

III. Basic Assumptions

1. It was assumed that the added effect of radiant heat should cause a greater physiological strain and thus result in diminished work capacity and greater loss of productive work time.
2. It was also assumed that any recorded physiological strains were a result of the work being performed and that the ambient temperature, relative humidity, and radiant temperature recorded formed the environment of the work task.
3. The assumption was also made that the work load represented a moderate, submaximal level of work as determined by pretesting evaluation.
4. It was finally assumed that the pulse rate and rectal temperature were proper and sufficient

measures of physiological strain resulting from the work and working conditions; also, that these measures were acquired with very little inconvenience on the part of the subject.

IV. Limitations of the Study

1. Only four subjects were tested in a limited range of ambient temperatures, radiant heat, and low humidity for test periods of 50 minutes.
2. No control was possible over the acclimatization effects outdoor activities might have had, though the temperatures during the testing period should have had no effect.
3. Only the pulse rate and the rectal temperature were recorded during each testing session. No attempt was made to determine sweat rate, effect of clothing, or any other physiological measure.
4. The task of stepping to a prescribed cadence for a test period of 50 minutes was a very monotonous work task. The only diversity was the recording of pulse rate and rectal temperature every five minutes, and the interchange of conversation.

V. Definitions

The following terms are defined as they were used in this study.

Acclimatization. "Acclimatization is the physiological response of the organism that is associated with repeated exposures to environmental stress" (6).

Ambient temperature. The air temperature around the working man as recorded by a dry bulb thermometer.

Physiological strain. The change in the homeotherm brought about by environmental and physical stress, the alteration in physiological function to maintain temperature, and the degree to which the change is effective (6).

Radiant heat. The temperature radiated by an infrared source and measured by a black globe thermometer. This method of heating is distinguished from conductive or convective methods since rays are the means of heat transmission.

Work capacity. The maximum work intensity that is consistent with a steady state and within optimal cardiovascular and respiratory function limitations. Approximately 50 per cent of human work capacity is the amount which can be undertaken successfully for a full work day (6).

CHAPTER II

SURVEY OF RELATED LITERATURE

There has been considerable interest recently concerning the physiological strains produced in man while working in various environments. The following survey represents the many works done concerning hot environments and should demonstrate both the diversity of interest and the currently accepted theories of researchers in this area.

In a review of materials concerning climate and exercise, Buskirk and Bass (14) state that exercise in the heat involves two stresses, each with a different requirement for blood flow. The exercise itself requires increased blood flow to the working muscles, while the environmental heat causes the thermo-regulatory mechanism of peripheral vasodilatation to increase, thus demanding more blood there as well. For the unacclimatized man, these two demands may result in incipient circulatory shock, similar to what he would suffer if he had hemorrhaged. In addition, temperature regulation suffers appreciably and hyperthermia becomes a distinct danger. Heat acclimatization will reduce the chance for these occurrences. After a relatively short period of exposure to heat and working in the heat, physiological adjustments are made which enable the individual to

work with a lower body temperature, a lower heart rate, a more stable blood pressure, and a decreased metabolic cost.

Consolazio, Johnson and Pecora (6) cited Johnson for his summarization of ideal conditions for the best performance of men working in heat. These conditions are of three major types. First of all, general conditions include no chronic or acute debilitating diseases and good general physical condition. Secondly, heat balance includes complete acclimatization for the particular environmental conditions and excessive rates of work, and as little clothing as consistent with protection against radiation and trauma. Thirdly, nutrition includes maintenance of complete hydration hour by hour, maintenance of adequate intake of salts and carbohydrates, total energy, and water soluble vitamins.

Durnin et al. (8) conducted an experiment with acclimatized infantry soldiers in an attempt to determine whether or not increasing environmental temperature and humidity increases the metabolic requirement for standard physical work. The heart rate, rectal temperature, and sweat rate means all showed a significant increase in the heat but there was no difference between hot/dry and hot/wet climates. Energy expenditure was calculated from pulmonary ventilation and oxygen extraction from inspired air. It was found that pulmonary ventilation increased in the heat whereas oxygen extraction decreased. As the

pulmonary ventilation increased to a greater extent than the oxygen extraction decreased, the net effect was an increase in energy expenditure. Thus it was concluded that the energy metabolism of men marching at a constant speed with various loads was increased in both hot/dry and hot/wet climates as compared with a temperate climate. This increase amounted to nine per cent in the hot/dry climate and five per cent in the hot/wet climate.

Consolazio et al. (5) compared the metabolic rates of seven young men performing three levels of physical activity at three environmental temperatures--70 degrees F, 85 degrees F, and 100 degrees F. It was found that there was a significantly higher metabolic rate for the men when working at 100 degrees F than at 85 degrees F and 70 degrees F. The findings thus indicated that the metabolic rate of a fixed physical activity is increased in the heat and that this increase is not due to acclimatization or training.

The question of the benefits of overhydration for men working in the heat was considered by Moraff and Bass (18). Thirty volunteers walked on the treadmill on two successive days in a temperature of 120 degrees F dry bulb/80 degrees F wet bulb. For the first walk, the men drank 2000 ml of water before and 1200 ml of water during the exercise. For the second walk, the men had no water before and 1200 ml of water during the exercise. The

overhydration resulted in significantly lower rectal temperatures and pulse rates and significantly higher sweat rates. This work was followed by acclimatization of two matched groups of six men in the overhydration and non-overhydration conditions tested. It was found that overhydration did not affect the pattern of acclimatization to heat, and conversely, heat acclimatization did not alter the previously described acute response to overhydration. Thus it was concluded overhydration is beneficial to men working in the heat.

The heat reactions of 20 Caucasians and 22 Bantu males were compared by Wyndham (22), first in the unacclimatized state and then in the acclimatized state. The performances of the unacclimatized Bantu were superior to those of the unacclimatized Caucasians. In this state, the mean rectal temperature was significantly lower for the Bantus but there was no significant difference between the mean heart rates and mean sweat rates. After a period of training, both groups were re-tested in a highly acclimatized state. Results then showed both groups to be significantly different in their reactions to heat than they had been previously. Now, however, there was no significant difference between the two groups in any of the physiological measures taken. Thus, in an acclimatized condition, there was no racial difference in the ability

to perform work in the heat.

Edholm, Adam, and Fox (9) observed the post-work pulse rate and body temperatures of subjects in both cool and hot environments. The subjects worked in the cool environment first and then in the hot environment for acclimatization. Both pulse rate and body temperature were higher in the first exposures to heat than they had been in the cool conditions. After some acclimatization, body temperatures reduced to those received during work in the cool environment. However, pulse rates in the heat were always above those observed in the cool conditions.

Acclimatization to heat begins with the first exposure and is well developed in four to seven days according to Buskirk and Bass (14). Garden, Wilson and Rasch (11) concluded, however, that $1\frac{2}{3}$ hours of daily heat exposure for 10 days was the minimum time necessary for acclimatization to occur. They tested 38 subjects by a modified Balke treadmill test after they were trained in a hot-wet environment. The subjects were divided into three groups for training and testing. The training environment was constant for each group but the length of work times varied. Group I worked 50 minutes and rested 10; group II worked 80 minutes and rested 20; and group III worked 100 minutes and rested 20. Groups II and III made the only significant decreases in pre-exercise rectal temperature

and working heart rate, while sweat loss was significantly elevated for all groups. The Balke test results showed improvement in all groups for the first week only, indicating the improvement in cardiovascular response to work in heat occurred primarily during the first week. No plateau of rectal temperature was observed for any group, thus there was no achievement of a thermal equilibrium as would be expected in hot-dry conditions. Other conclusions drawn from this study were that adaptation to hot-wet environments is different from that to hot-dry environments, and that acclimatization should be more clearly defined and used only when environmental and physiological factors are precisely stated.

Brouha et al. (4) found that for essentially equal oxygen consumptions the heart rate and the cardiac cost for men and women were markedly greater in higher temperatures both during work and recovery. In this study, it was also concluded that warm-humid environments were more stressful than warm-dry environments.

Fox (10) reached the conclusion that the thermal stress of a hot climate is determined by the combined effects of all the climatic factors which influence the loss or gain of heat by the body. These factors include air temperature, humidity, air speed, radiation, and barometric pressure. The effect of a hot climate on a particular

individual depends on even more factors which characterize the state of the individual. These factors include energy expenditure, clothing, body size, degree of acclimatization, duration of exposure, and general health.

Brouha (2) states:

In work at high temperatures, for a certain amount of energy required by physical work, an increased physiological effort is needed to maintain the body temperature as close as possible to its normal level. Working efficiency is also affected by the environment and carefully controlled experiments and observations have shown a reduction in output when the temperature increases.

A number of relevant conclusions are formed by Brouha from his experiments. They include: a) stress on the cardiovascular system increases with the ambient temperature; b) heart rate during work and recovery varies according to work load, ambient conditions, and sex; c) in warm environments lactic acid accumulation is not the limiting factor to maximum performance; d) work under warm-dry conditions appears to be performed with a slightly lower oxygen consumption than in other environments; and e) recovery to a heart rate of 110 beats per minute is not sufficient to compensate for the stress of work.

This review demonstrates the fact that there is a good deal of information available concerning the effects of work in the heat on man. Despite the displayed diversity of interest and the functional conclusions, there is no information specifically noting effects of radiant heat.

This review has thus indicated a need for further study in the general area of heat stress and specifically concerning the effects of radiant heat.

Additional review is forthcoming in Chapter III. Sections 3, 4, and 5. This shall be relevant to the selection of the work task, selection of physiological measures, and selection of the indexes.

CHAPTER III

METHODS AND PROCEDURES

I. Subjects

Four volunteer subjects from the Health and Physical Education major's program and staff of the University of Montana were involved in the study. All subjects were Caucasian. Each was in excellent health and good physical condition, without handicap relevant to the work task performed. No other work was performed by the subjects throughout the testing which might have had acclimatizing effects, or which might be termed training for the work task of this study. Resting pulse rates were recorded periodically before test sessions but not as a regular part of the testing routine. Subject D. H. generally had a resting pulse rate of 76; R. G. a resting pulse of 64; L. G. a resting pulse of 72; and R. S. a resting pulse of 56. The physical characteristics of the subjects are shown in Table I.

II. Equipment and Apparatus

All major articles of testing equipment and apparatus are described below with brief explanations of their selection and use. See Figure 1.

TABLE I
PHYSICAL CHARACTERISTICS OF SUBJECTS

Subjects	Weight Pounds	Height Inches	Age Years
D.H.	150	64	21
R.G.	205	70	23
L.G.	175	71	22
R.S.	195	72	25
MEANS	181.25	69.25	22.75

Heat chamber. A heat chamber was utilized for all the heat-effected testing sessions. The temperature inside the chamber could be thermostatically controlled over a range of 50-250 degrees F. Throughout a test session, the temperature was constantly observed and easily adjusted if necessary, either by the thermostat or by increased ventilation from opening the door. Space within the chamber was very adequate with measurements of 12 feet long x nine feet wide x seven feet high, so that all equipment could be conveniently fitted in with no conflict for movement of subject or technician.

Reflector infrared lamps. Four 250 W infrared lamps were mounted vertically on a portable stand and were utilized as the radiant heat source for the study. They were mounted at a height which would expose the subject's torso

especially to the heat, though the head and legs were generally heated also. Controls for the lamps allowed settings of "Dim," "Half," and "Brite." The "Brite" setting was always used since all lamps were thus lighted and the greatest amount of heat was produced.

Water's thermistor. Two probes were used with this battery-operated apparatus during each session. Balance and scale were previously set on the thermistor so that both rectal temperature and air temperature could be accurately determined simply by proper selection of the outlet number on a manually operated dial. Both centigrade and Fahrenheit degrees could be read from a scale on the front of the apparatus. Centigrade was most easily read for rectal temperature determination and that scale was used for that purpose throughout the study. The Fahrenheit scale was most applicable for air temperature readings and was used throughout the study for that purpose.

Wooden step. In determining the work task for this study, it was found that a wooden step approximately 21 centimeters in height was best for the submaximal work effort desired. The top dimensions of the step were 18 inches in width and 32 inches in length so it was not a difficult surface to reach or retain balance on. It was easily portable to and from the testing area and quite manageable within the testing area, resting firmly in place once positioned.

GraLab universal timer. This timer has a large open face with both a minute hand and a sweep second hand. The minute hand can be set for any number of minutes within an hour and it then runs in a counter-clockwise direction in order to show the remaining number of minutes in the test period. It is electrically operated, quite accurate, and very easily utilized.

Sling psychrometer. This apparatus consists of two thermometers, one dry bulb and one wet bulb; a swivel handle; and a protective shield. Temperature values were read from the psychrometer after it was spun through the air for about a minute. A relative humidity table compiled by the United States Weather Bureau was available from which the relative humidity could be read very easily using the temperature values from the psychrometer. This process was followed about midway through each testing session.

Black bulb thermometer. A black bulb thermometer was constructed from a six-inch copper ball, a rubber one-hole stopper, and a mercury Fahrenheit thermometer. The copper ball was painted flat black and the stopper with the thermometer inserted into it. Thus the airtight, flat black globe thermometer would accurately register radiant heat temperature. Air movement would result in lower temperatures and was therefore considered by this measuring instrument as well. Previous to test sessions which would be affected by radiant heat, this thermometer was hung

12 inches from the infrared lamps for a period of 15 minutes in order to determine the heat emitted at the distance the subject would be working. Previous to test sessions not to be affected by radiant heat, this thermometer was hung for 15 minutes in the area where the man would be working in order to determine if there was any radiant effect even without the infrared source.

Metronome. A spring-operated metronome was used to set the cadence for stepping throughout the 50-minute work period. It was set at 90 beats per minute or 22.5 steps per minute, each beat representing the time one foot should be contacting the step or floor in the stepping process. This rate was selected with the step height as a submaximal work effort. Throughout the testing session, the metronome was checked periodically to assure the setting at 90, and it was rewound at least once each session to assure a steady cadence.

Clothing. Subjects each wore a dark cotton long-sleeved shirt, denim trousers, tennis shoes, and an aluminum hard hat in each of the testing sessions. This was to approximate, within reason, the regulation clothing worn by firefighters.

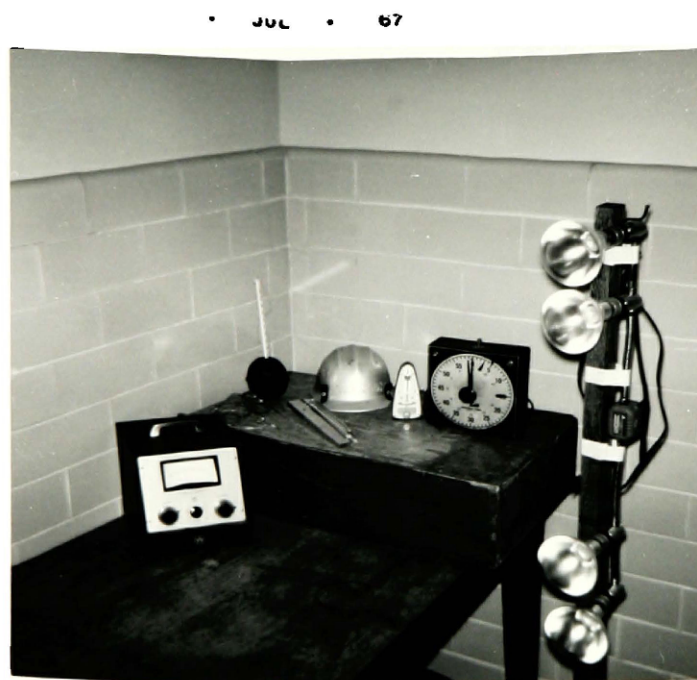


Figure 1. Major Articles of Testing Equipment.

III. Selection of Work Task

Sharkey (20) cited a number of studies which indicated that firefighting tasks have an energy cost between five to 10 Kcal/min. or one to two liters of oxygen per minute. This range of values lies well within the abilities of most normally healthy men. In order to select a work task for this study which would cost about 1.5 liters of oxygen per minute, two subjects representing the physical extremes in the study were tested with various height steps and stepping rates. The step test took five minutes. During the final minute, expired air was collected in a Douglas bag and its volume measured in a gasometer. The Scholander method of gas analysis, as discussed by Conso-lazio, Johnson, and Pecora (6), was used to determine the percentage of oxygen and carbon dioxide in the expired air. This total process continued until a step height and stepping rate was found which represented an average energy cost of about 1.5 liters of oxygen per minute.

The step test was initially selected since of the available laboratory tasks it most closely approximates a practical work task for the firefighter. The bicycle ergometer was not considered because of its impractical nature, and the treadmill could not be considered because it could not be moved readily to and from the heat chamber.

IV. Selection of Physiological Measures

The pulse rate and rectal temperature were selected as appropriate measures of physiological strain. Wyndham et al. (23) concluded from their work with acclimatized and unacclimatized subjects that heart rate and rectal temperature provided the most complete and clear indications of significant differences. Rectal temperature alone provided slight evidence of acclimatization difference, and inconclusive evidence was provided by sweat rate. Other researchers have evaluated the use of the pulse rate as a predictor of energy cost. McDonald (16), for example, concluded from his study that there is a linear relationship between pulse rate and oxygen consumption, and that pulse rate can be a useful predictor of metabolic rate. Brouha et al. (3), however, concluded that this linear relationship does not hold when dissipation of body heat is impaired by excessive clothing or by a thermally stressing environment. Under these conditions, oxygen consumption remains the same and the heart rate is elevated in response to the need for thermal regulation.

Since the subjects were unacclimatized, the use of the rectal temperature seemed advisable. Most researchers have considered it and Edholm, Adam, and Fox (9) specifically noted a rise in body temperature during work in heat until some acclimatization took place.

Sweat rate consideration was disregarded due to the

lack of appropriate collection equipment and the lack of foreseeable functional use by officials in field conditions. Clothing effects were also disregarded since apparel was a constant for all subjects and since regulations determine the clothing to be worn by firefighters.

During the testing, pulse rate was taken manually at the wrist of the subject by the technician for a period of 15 seconds. This rate was then multiplied by four and this value then recorded as the minute heart rate. This method of taking the pulse was checked for accuracy in the first trials by telemetering the heart rate at the same time a technician took the subject's pulse. At times, two technicians took the subject's pulse. In both instances the values received were compared in order to better prepare the technicians for accurate determination of a subject's pulse rate. The rectal temperature was read directly from the centigrade scale on the Water's thermistor and recorded to the nearest tenth decimal place. A rectal probe had been inserted by the subject prior to beginning work to a depth of about three inches to insure consistent and accurate temperature readings.

V. Selection of Indexes

A number of indexes were evaluated for use in this study. The Effective Temperature Scale developed by Houghton and Yaglou in 1923 was eliminated since Brouha (2), in

discussing the shortcomings of the ET index, noted that it was established for subjects at rest or doing only light work. It also does not consider the effects of radiant heat, which is a basic consideration of this study.

Buskirk and Bass (14) evaluated McArdle's Sweat Rate Index which is a predictor of sweat rate from ambient weather information and the metabolic rate of the man. Once again radiant heat is not a consideration of this index. Administration of this index involves a much longer period of time than is practical for field conditions and also is limited to application to light work loads. An index by Lee is also discussed by Buskirk and Bass but it also neglects radiation effects. Other researchers are mentioned for theoretical analysis of heat stress which are not yet proven or in common use.

Belding and Hatch (1) developed a heat stress index which they declared was 1) to provide a means for evaluating the components of heat stress in any environment; 2) to determine what, if any, systematic relationship exists between these components of stress and the resulting physiological strains; and 3) to assign to the stresses index values which have meaning in terms of human endurance for heat. This index was held in high regard by other investigators previously mentioned (2, 14) and was selected for use in this study.

Minard, Belding, and Kingston (17) considered the

wet bulb-globe temperature (WBGT) index of Yaglou and the heat stress index (HSI) of Belding and Hatch for use by the Marine Corps. Their work was an attempt to choose an index which might reduce or avoid the incidence of heat casualties among recruits and trainees. The need was recognized since in 1954 and 1955 the index in use was insufficient. After evaluation of the two indexes mentioned above, it was recommended that the WBGT index be adopted. After its adoption in 1956, a significant decrease in the incidence of heat casualties was noted despite the hotter conditions in 1956 as compared to 1955. This index was also chosen for evaluation in this study.

As previously indicated, other indexes and theories exist. However, for the purposes of this study and for the related needs of the Forest Service, only the HSI and WBGT indexes were considered practical for this evaluation.

VI. Experimental Schedule and Procedure

Testing began near the end of January, 1967, and extended into April. No daily pattern of testing was incorporated other than to avoid two exposures to heat for any subject within a period of seven days. This was to avoid any acclimatization to the hot environment. A variable program of testing was incorporated so that no two subjects followed the same testing schedule.

Appointment was made with subjects one day in

advance for a morning hour. They were advised to get a good night's sleep, to avoid a heavy breakfast and coffee, and to arrive early and in a relaxed condition.

On a test day, the subject was advised upon arrival to dress, insert the rectal probe to a depth of about three inches, and to relax. During this time, all equipment was set up and rechecked, and the temperature for that trial was regulated. If appropriate, the radiant temperature of the infrared lamps was checked at this time.

When the subject was judged relaxed and comfortable and the equipment and temperature in readiness, the subject was advised to enter the heat chamber. As he stood in position to begin the test, the rectal probe was quickly fitted to the thermistor, the timer set, and the metronome started. Within about one and one-half minutes of exposure to the environment the subject was working. See Figures 2 and 3.

The subject stepped at a cadence of 90 beats or 22.5 steps per minute for five minutes. If this cadence was forgotten momentarily, the subject was corrected by the technician to slow or speed up his stepping rate. At the end of five minutes, a 20-second halt was called for pulse rate and rectal temperature readings. Immediately after these recordings were made, work was resumed. Such halts for physiological measurement readings were called on each five-minute interval of the 50-minute test.

The test continued for 50 minutes unless the subject

pulse rate reached 180 beats per minute or the rectal temperature reached 102.5 degrees F. These limits are discussed by Consolazio, Johnson, and Pecora (6) and were determined by Iampietro and Goldman (13) to be the physiological limits within which man can work efficiently. When one of these readings was reached, the test was terminated and recovery begun. Recovery in this instance and after a full test period was the time necessary for the pulse rate to return to 110 beats per minute. For recovery, the subject was seated in the same environment, minus the effect of the radiant heat.

All information, including the subject's name, time of day, room temperature, radiant temperature, humidity, pulse rate and rectal temperature at each five-minute interval, and recovery time was recorded on a standardized data sheet prepared for the purpose of this study. See Appendix A.

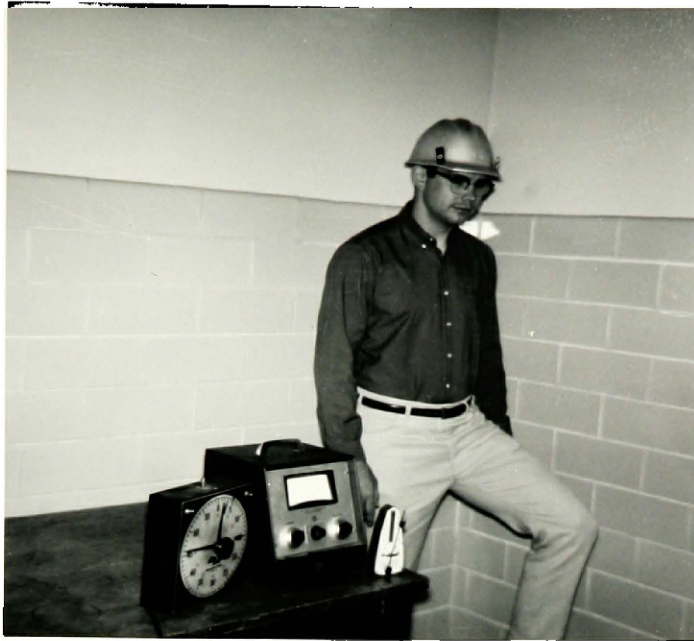


Figure 2. Subject Working in Ambient Conditions.

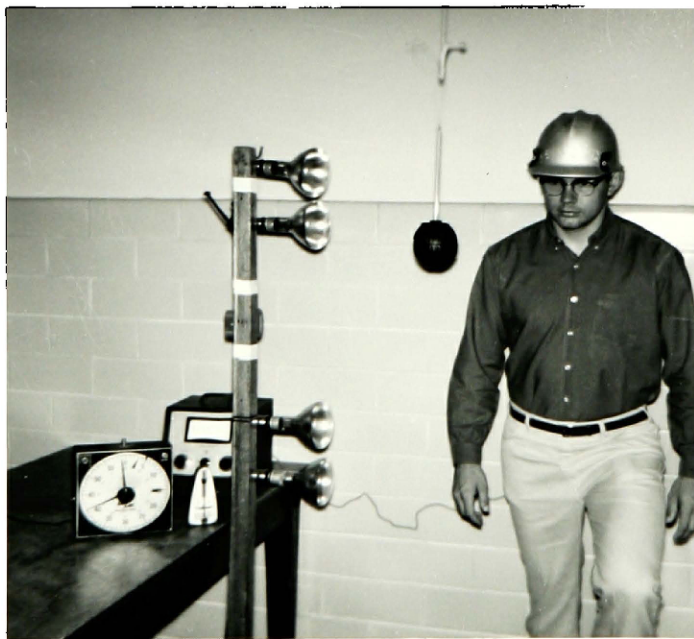


Figure 3. Subject Working in Radiant Heat.

CHAPTER IV

ANALYSIS AND DISCUSSION OF RESULTS

I. Introduction

The data which was collected from the subjects while working in five environmental conditions is presented in Appendix B.

Analysis of a statistical basis is limited due to the very nature of this study. The number of subjects was small and the temperature conditions in which they were working were strictly dictated. Both correlation analysis and tests of significance would be somewhat irrelevant for the purposes of this study. This analysis shall utilize only the statistical means of the collected data. See Table II.

Two general interests are included in this analysis. The first is a graphic display and discussion of the increased physiological strains produced in men working in stressful environmental conditions. Secondly, two indexes, previously introduced and discussed, are tested for their applicability for use with data such as that collected in this study.

Throughout this analysis and discussion, the various environmental conditions will be referred to as room

TABLE II

MEAN PULSE RATES AND RECTAL TEMPERATURES FOR THE SPECIFIC TEST CONDITIONS

		Intervals										Recovery in Minutes
Condition		5	10	15	20	25	30	35	40	45	50	
Room	Pulse	119	126	129	131	135	137	136	141	140	139	1.25
	Rectal	36.7	36.8	36.9	37.0	37.2	37.2	37.3	37.4	37.5	37.6	
90	Pulse	109	126	133	136	139	141	145	147	146	146	1.31
	Rectal	36.7	36.8	36.9	37.0	37.0	37.2	37.3	37.4	37.5	37.5	
90/*	Pulse	117	131	147	147	155	159	161	165	168	166	4.88
	Rectal	36.7	36.8	36.9	37.0	37.1	37.2	37.3	37.4	37.5	37.6	
110	Pulse	126	138	143	150	153	163	170	177	178**	180***	14.75
	Rectal	36.8	36.9	37.0	37.1	37.3	37.4	37.6	37.8	37.8	37.6	
110/*	Pulse	120	140	148	153	164	170	177	184****			13.69 ¹
	Rectal	36.8	36.8	36.9	37.1	37.3	37.5	37.6	37.8	--	--	

*/ = Plus radiant.

**Results from two subjects.

***Results from one subject.

****Results from three subjects.

¹Noted in the text, page 33.

temperature, 90 degrees, 90-plus radiant, 110 degrees, and 110-plus radiant. Room temperature refers to 70-degree ambient conditions. The other degrees and terms are self-explanatory conditions.

II. Analysis of Data

The following discussions will relate to Figures 4 through 8. Figures 4, 5, and 6 demonstrate physiological responses while Figures 7 and 8 demonstrate WBGT index score relationships to the physiological responses.

Physiological Strains Produced During Work in Hot-Dry Environments

Pulse rate means and recovery times for each environmental condition are shown in Figure 4. The general trend displays the expected increased physiological strain as a result of work in more severe environments. This trend is clear in the 15-minute interval, though the 90-plus-radiant and 110-degree responses do not clearly distinguish themselves until the 30-minute interval. The room-temperature response in the first five minutes is probably due to anticipation and other extenuating conditions. Most subjects performed this task early in the testing and may have had other influences affecting pulse rate until well into the work period when, as notable at the 15-minute interval, the work load becomes the chief determinant and response is as might be expected. Both room-temperature and 90-degree responses display low pulse rate maximums and quick recovery times.

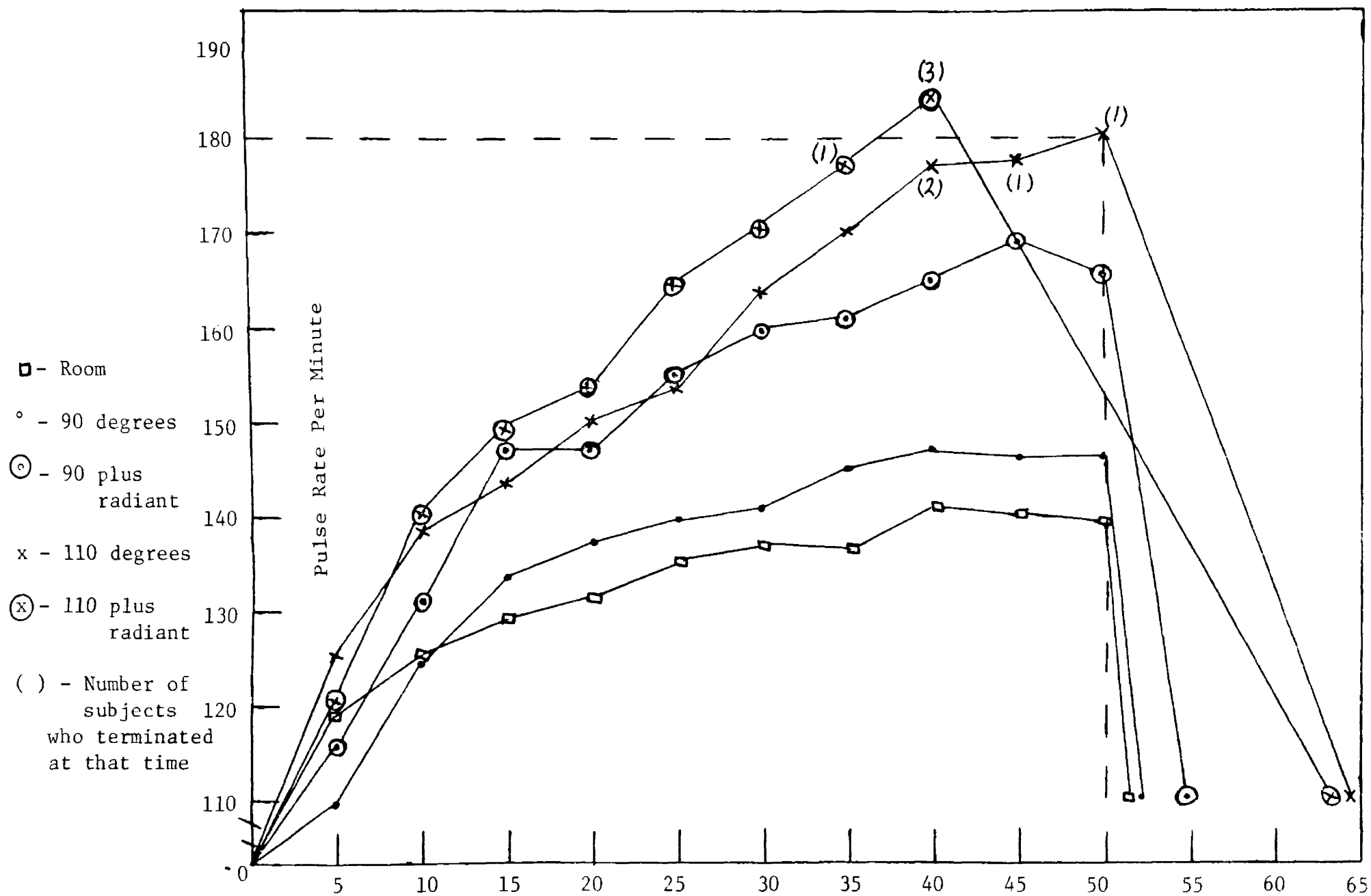


Figure 4

Pulse Rate Means and Recovery Times
for Each Environmental Condition

All other conditions show much more severe effects, however. Ninety-plus radiant results in a mean pulse rate as much as 22 beats per minute higher than that received at 90 degrees. In 110-degree and 110-plus-radiant conditions, the pulse rate climbed steadily and rapidly so that all but one subject terminated the 110-degree condition before the end of the work period and all subjects had terminated the 110-plus-radiant condition at least by the 40-minute interval in the work session. As it is noted in Figure 4, in the 110-degree environment two subjects terminated in the 40-minute interval, one in the 45-minute interval, and one subject terminated at the end of the work period. In 110-plus-radiant conditions, one subject terminated in the 35-minute interval and all others terminated in the 40-minute interval. It is noteworthy that the mean pulse rate in this last instance was 184 beats per minute. Pulse rates as high as 188 beats per minute were not uncommon.

The added effects of radiant heat at both 90 degrees and 110 degrees are obvious. In both instances there was a higher physiological strain with decreased work capacity as compared to the strain noted in ambient conditions. The decreased work capacity is noted in 90-plus radiant as increased recovery time, while in 110-plus radiant it can be noted in the fact that no subject could work in the environment more than 40 minutes without attaining the 180 heart rate criterion.

The recovery times recorded from 110 degrees and 110-plus radiant may be confusing without the realization that while 110-plus radiant was a much more severe environment and the pulse rates rose faster and higher, more actual work was performed in the 110-degree condition, thus resulting in necessarily longer recovery times.

Figure 5 graphically displays the rectal temperature means recorded for each environmental condition. In all conditions, the rectal temperature displays a steady and constant rise throughout the work period. This measure of physiological strain does not display a marked difference between severity of conditions until the 20-minute interval. Even then, 90-plus-radiant recordings remain very close to room and 90-degree rectal temperatures, whereas the pulse rate for 90 plus radiant was very much above that of the other two conditions. Rectal temperatures recorded in the 110-degree and 110-plus-radiant environments rose rapidly above those of the other conditions but without a great difference between them. In general, there seems to be little or no actual pattern of results other than a steady increase in all conditions, and since rectal temperature values for less severe conditions are higher than those from more severe conditions on several occasions. Note once again the indication of terminations of subjects so that in the 110-degree condition only two subjects contributed to the mean in the 45-minute interval, and only one in the last time interval.

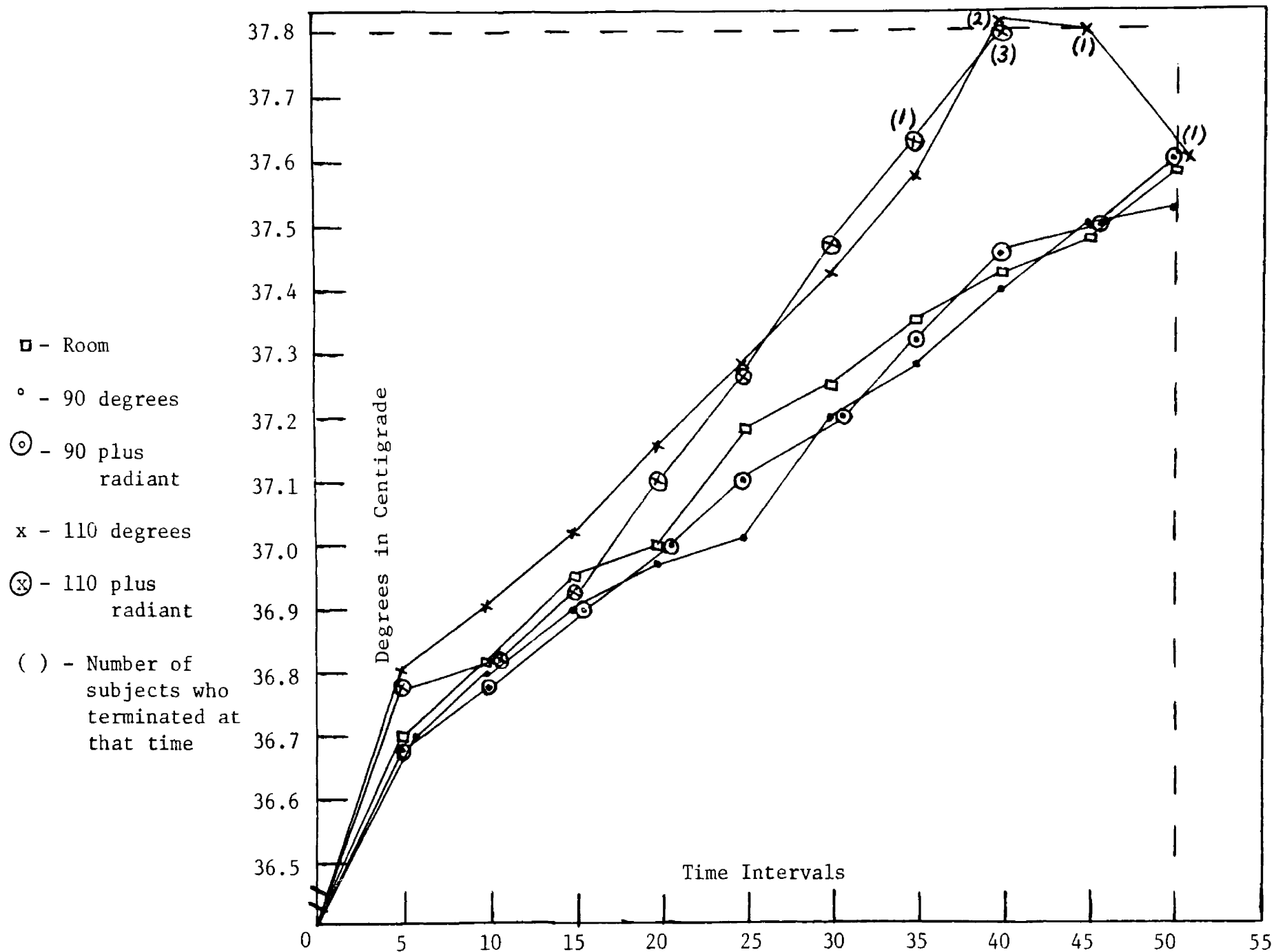


Figure 5

Rectal Temperature Means for
Each Environmental Condition

The relation of pulse rate to rectal temperature during the 25-, 30-, and 35-minute intervals is shown in Figure 6. At no time interval is the relationship linear. However, the steady upward movement of physiological measures in each environmental condition throughout these 15 minutes is noteworthy. Higher rectal temperatures received in some less severe conditions seem to be responsible for the odd pattern. Thus, for all environmental conditions none of these time periods display a tremendous rise in physiological strain. Increases seem to be rather constant over this exemplary time sequence.

Index Results

Results from the use of the WBGT index are presented in Table III. In computing these values, the wet bulb temperature was multiplied by 0.7; the dry bulb temperature was multiplied by 0.1; and the globe temperature was multiplied by 0.2. Results from these multiplications were then added together for the WBGT value.

According to Minard, Belding and Kingston (17), WBGT values of 85-87.9 indicate environmental conditions when only acclimatized and physically fit individuals should continue active outdoor work, while values of 88 and over indicate environmental conditions when all active outdoor work should be suspended. Values calculated for the environmental conditions noted in this study indicate that three conditions, 90 plus radiant, 110 degrees, and 110 plus radiant are all

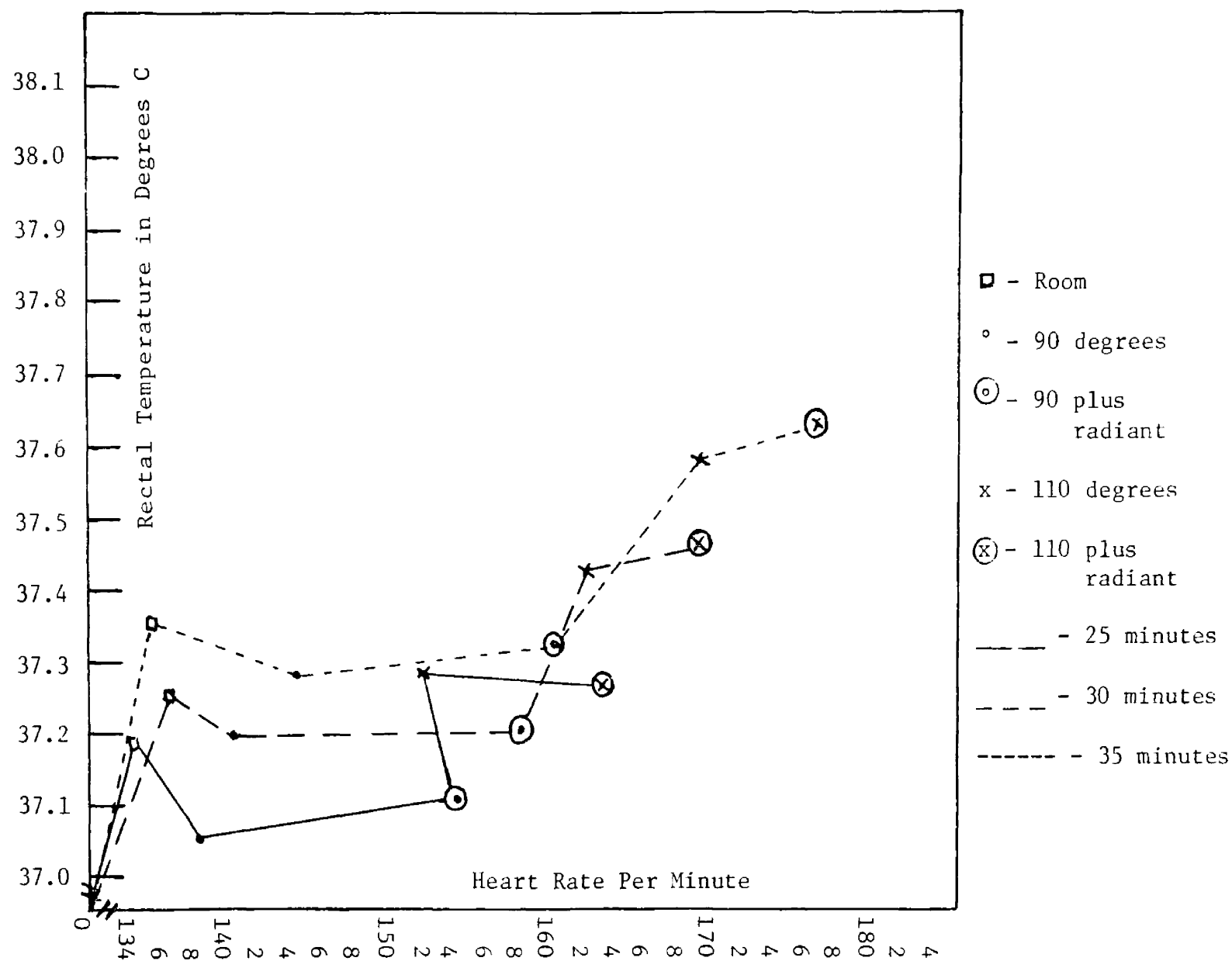


Figure 6

Relation of Pulse Rate to Rectal Temperature at
25, 30, and 35 Minutes

above the 88 value. No condition was in the 85-87.9 range of values.

TABLE III
COMPUTED WBGT INDEX VALUES

Environmental Condition	Temperature Values			WBGT Values
	Wet Bulb	Dry Bulb	Globe	
Room	51	70	70	56.7
90 degrees	69	90	90	75.3
90 plus radiant	67	90	163	88.5*
110 degrees	84	110	110	91.8*
110 plus radiant	83	110	164	101.9*

*Values are above those advised by Minard, Belding, and Kingston (17) to be safe for continued work.

The WBGT index results are related to the pulse rate during the 35-minute interval in Figure 7. The steady climb indicates a very close relationship. From the test experience and WBGT results, it is obvious the WBGT index accurately distinguished the more severe conditions. Figure 8 displays the WBGT index results as related to the rectal temperature in the same time interval. The pattern is much less conclusive than that of Figure 7 except for the 110-degree and 110-plus-radiant conditions. The indication is that pulse rate is more nearly related to WBGT index values

than is rectal temperature.

The HSI index was found applicable to the ambient conditions only. Radiant temperatures used in this study were above those accounted for in the index. From those conditions which could be used in the HSI, room temperature had an index value of 40, 90 degrees had an index value of 115, and 110 degrees had an index value of 180. It is recommended by Belding and Hatch (1) that when heat stress exceeds 100 the implication is that heat balance may not be maintained and that the sweating mechanism may be overtaxed so that the standard man, in this case a man about five feet eight inches tall who weighs 154 pounds, will not tolerate prolonged exposure.

III. Discussion of Results

The results of the study suggest that pulse rate was the most predictable measure of physiological strain produced in man working in hot/dry environments. Since the work load was constant, it seems rational to assume that the distinct rises in pulse rate during work in greater heat conditions over those values received in room temperature were caused by the more severe environmental conditions. This suggestion is supported by the findings of a number of investigators (4, 9, 15, 21).

Also suggested in the findings from this study is that radiant heat produces much greater physiological

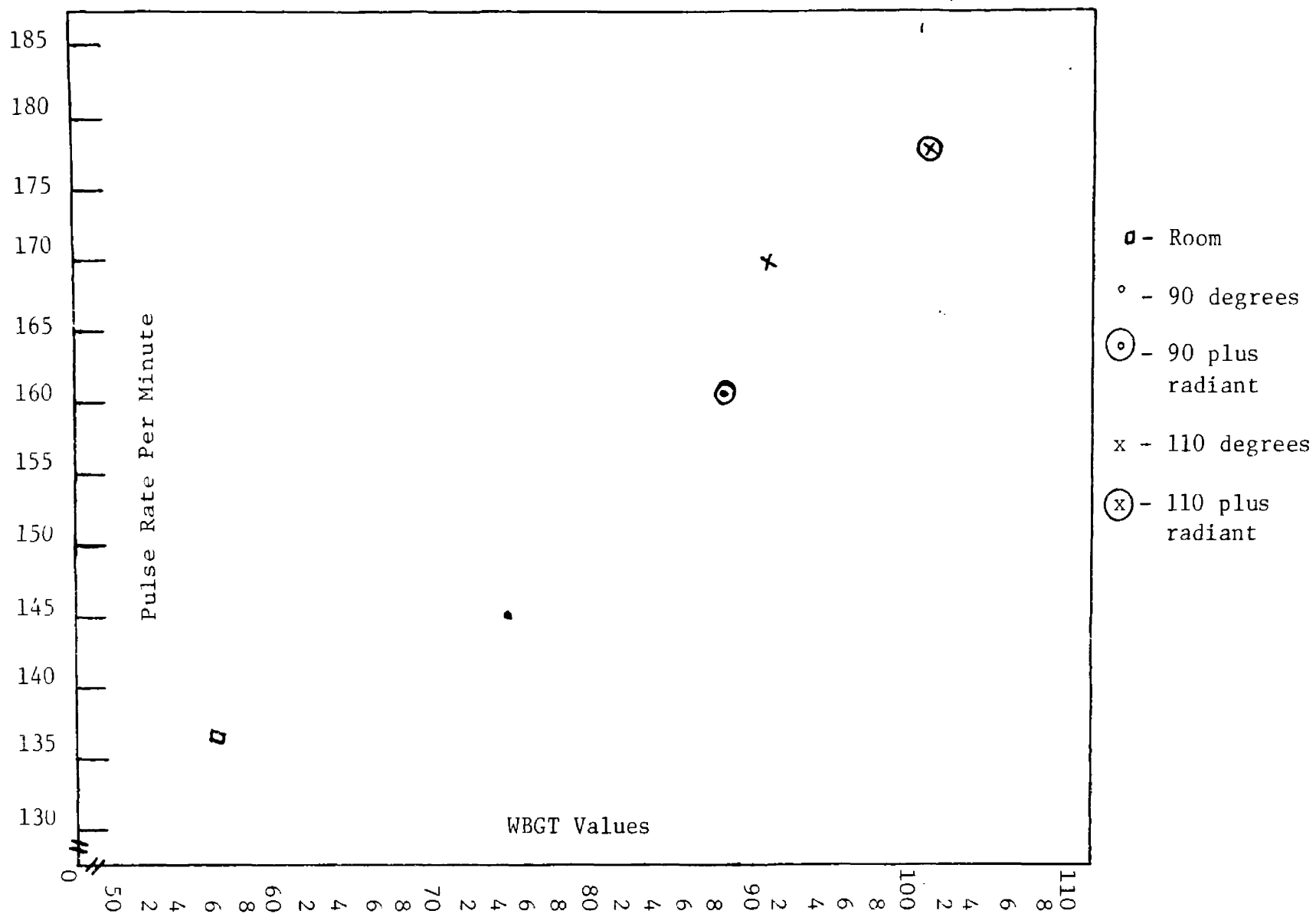


Figure 7

WBGT Index Results Related to the Pulse Rate
in the 35 Minute Interval

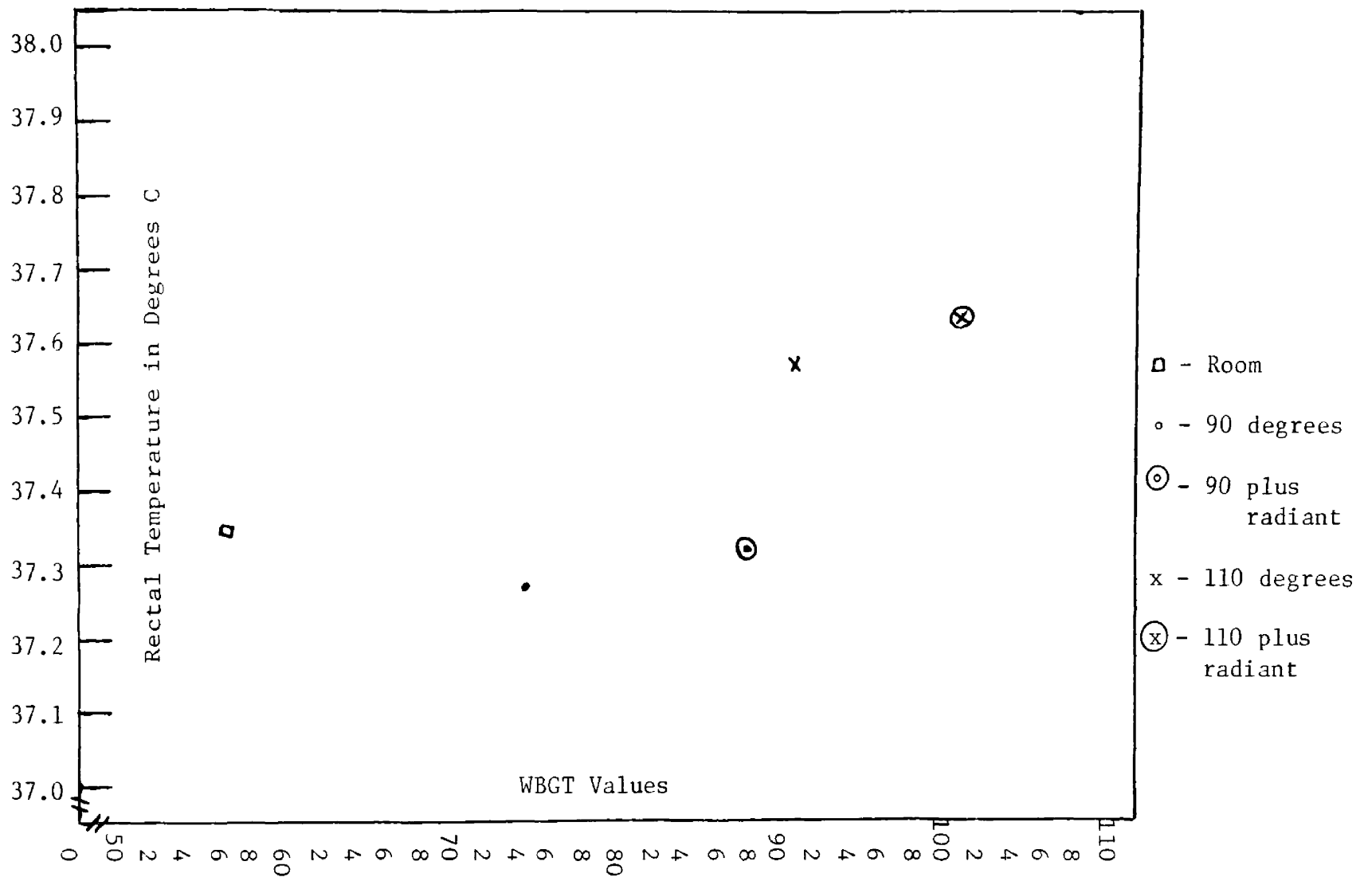


Figure 8

WBGT Index Results Related to the Rectal Temperature
in the 35 Minute Interval

strains than does the ambient heat alone. This is especially evident in the difference between the pulse rates of 90 degrees and 90 plus radiant. The more rapid rising, higher values of 110 plus radiant over those pulse rate values at 110 degrees also seem to support this idea.

Rectal temperatures recorded in this study also relate closely to previous investigations (9, 12, 19). The elevations in rectal temperature appear to be much less dependent on environmental conditions until quite severe conditions are encountered. That is, only the rectal temperatures recorded during 110 degrees and 110 with radiant were very much above the very similar recordings taken in room-, 90-degrees, and 90-plus-radiant conditions.

Any effects radiant heat might have had on the rectal temperature are inconclusive. It might be suggested, in fact, that the radiant temperature caused no increase in this measure of physiological strain over the strain already recognized from ambient conditions. It is generally suggested that rectal temperature is much more dependent on the work load being performed than on the environmental temperature unless unacclimatized men are working in high ambient temperatures. This seems to be the case in this study. The effects are, of course, unavailable for what might occur in these subjects in an acclimatized state.

From the investigation of the usefulness of either the WBGT or HSI index for use with environmental conditions

as encountered in this study, it is suggested the WBGT index is far superior. It is much easier to use as well as being quite adaptable to all levels of wet bulb, dry bulb, and globe temperatures. The HSI index showed a striking deficiency in the range of radiant temperatures which could be considered in fire fighting. It was, in fact, unusable for either of the relatively moderate radiant heat affected conditions of this study.

The black globe utilized in the WBGT measures radiant heat and considers air movement. However, the index does not include the metabolic heat load as the HSI does. This omission seems permissible under the conditions of fixed work load as employed in this investigation. Adjustments should be considered for higher or lower energy expenditures as might be encountered under actual working conditions.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. Summary

The purpose of this study was to determine the effects of hot-dry and radiant heat on physiological strains produced in man during submaximal work, and to relate these physiological responses to chosen indexes. In turn, these indexes were to be evaluated for their applicability for use with conditions such as those encountered in this study. This research was related to a recognized need of the United States Forest Service for determining the work capacity of men working on a fireline where both ambient and radiant heat are factors.

Four volunteer subjects were tested in five environmental conditions--room temperature, 90 degrees, 90 plus radiant, 110 degrees, and 110 plus radiant. A step test was selected as the submaximal work task and work periods were 50 minutes in length. Recordings of pulse rate and rectal temperature were made every five minutes throughout the test period and the recovery time to 110 heart beats per minute was recorded after termination of the work. Physiological limits of 180 heart beats per minute or a rectal temperature of 102.5 degrees were set so that if either measure of strain was recorded any time

during the test period the test was terminated at that point and recovery begun. Subjects were tested in the various stressful environments on a random basis to avoid very similar exposure schedules. Testing was spread over a long period of time, also, to avoid any acclimatization to heat or any training for the specific work task.

The means of the collected data were used in two general analyses. Graphic displays of the physiological strains measured in the various environments were made and discussed. Two indexes, the WBGT and HSI, were utilized and their values compared to the physiological strains recorded.

It was found that the pulse rates rose in a linear fashion over the length of the test period. In more severe conditions the pulse rate rose more rapidly and higher. Room-temperature and 90-degree recordings were similarly low with fast recovery times. Ninety plus radiant was much more stressful than 90 degrees as seen in the more rapid and higher rise in pulse rate. The 110-degree condition and 110-plus-radiant condition were much more stressful than any other conditions, the 110-plus-radiant condition being the most stressful of all. In these two conditions, all subjects' pulse rates reached 180 beats per minute at least by the end of the 50-minute period. The added effects of radiant heat at both 90 and 110 degrees showed great increases in physiological strain as measured by

pulse rate. Rectal temperature results were less dramatic, though the 110-degree and 110-plus-radiant conditions caused higher rectal temperatures than the very similar recordings received from room-temperature, 90-degrees, and 90-plus-radiant conditions.

Evaluation of the indexes showed the WBGT index to be superior for use with conditions as encountered in this study. The values of this index were displayed graphically in comparison to both pulse rate and rectal temperature recordings received in the various conditions.

II. Conclusions

The results of the study pointed out the following conclusions:

1. Pulse rate rises in proportion to the environmental stress, and greater pulse rates were received while subjects worked in more stressful environments.
2. From the physiological strains measured, additional radiant heat was noted to have produced a greater strain than ambient heat alone.
3. Rectal temperature alone did not indicate great variations in physiological strains produced in man working in stressful environments.
4. The WBGT index results were found to be in

linear relationship to recorded pulse rates.

5. Of the indexes tested, the WBGT index was found superior to the HSI index for use with environmental conditions of the type encountered in this study.

III. Recommendations

The findings of this study indicate that the pulse rate can be the most acceptable measure of physiological strain produced in working men in various environmental conditions. Further indications are that radiant heat causes a greater physiological strain on man working at a moderate rate than ambient heat alone. The test of indexes found the WBGT index to be most applicable to the needs of this study and for use with the types of environmental conditions encountered in this study. The results of the study have indicated the following recommendations:

1. Further research should be conducted with a variety of submaximal tasks in a greater variety of ambient and radiant-affected environments.
2. Additional research should be conducted with a concern for the most efficient measure of physiological strain in man working in high ambient and radiant-affected environments, and in hot-wet conditions.

3. Research regarding the effects of reflective and evaporative clothing in high ambient and radiant-affected environments should be undertaken.
4. Additional studies are needed which investigate the applicability of more indexes and the relationships of these index results to recorded physiological strains.

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APPENDIX

APPENDIX A

SAMPLE DATA COLLECTION SHEET

Subject _____ Time _____
Room Temperature _____
Radiant Temperature _____
Humidity _____

Time Interval	Pulse Rate	Rectal Temp.
5		
10		
15		
20		
25		
30		
35		
40		
45		
50 (T)		

Recovery Time to Pulse Rate 110/Min. _____

Notes of importance in regard to this performance:

APPENDIX B
RAW DATA FROM WORK IN FIVE ENVIRONMENTAL CONDITIONS

		<u>Room Temperature</u>										Recovery in Minutes
		Intervals										
Subject		5	10	15	20	25	30	35	40	45	50	
L.G.	Pulse	132	144	144	144	148	148	148	152	148	148	1.75
	Rectal	37.0	37.4	37.5	37.5	37.5	37.5	37.7	37.7	37.7	37.8	
R.G.	Pulse	120	120	128	132	144	144	148	156	156	156	1.25
	Rectal	36.9	36.9	37.0	37.2	37.4	37.5	37.5	37.5	37.6	37.7	
D.H.	Pulse	128	136	140	140	140	144	144	144	144	140	1.75
	Rectal	36.0	36.0	36.3	36.3	36.7	36.9	37.0	37.0	37.0	37.1	
R.S.	Pulse	96	104	104	108	108	112	104	112	112	112	.25
	Rectal	36.9	37.0	37.0	37.0	37.1	37.1	37.2	37.5	37.6	37.7	
		<u>90 Degrees</u>										
L.G.	Pulse	120	136	140	140	144	144	144	144	144	144	2.00
	Rectal	36.8	37.0	37.1	37.2	37.3	37.4	37.5	37.6	37.7	37.7	
R.G.	Pulse	104	136	148	152	160	156	164	168	168	164	1.50
	Rectal	36.5	36.6	36.7	36.8	36.9	37.1	37.2	37.3	37.4	37.4	
D.H.	Pulse	112	120	120	128	124	132	132	136	136	140	.75
	Rectal	36.9	36.9	37.0	37.0	37.0	37.1	37.1	37.3	37.4	37.5	
R.S.	Pulse	100	112	124	124	128	132	140	140	136	136	1.00
	Rectal	36.6	36.7	36.8	36.9	37.0	37.2	37.3	37.4	37.5	37.5	

APPENDIX B (Continued)

		<u>90 Plus Radiant</u>										Recovery in Minutes
		Intervals										
Subject		5	10	15	20	25	30	35	40	45	50	
L.G.	Pulse	128	148	148	148	160	156	156	160	168	164	4.75
	Rectal	37.2	37.4	37.4	37.5	37.6	37.7	37.7	37.9	38.0	38.0	
R.G.	Pulse	112	124	148	144	148	152	156	160	164	164	7.00
	Rectal	36.4	36.5	36.5	36.5	36.6	36.7	36.9	37.0	37.0	37.1	
D.H.	Pulse	120	128	152	152	164	164	168	176	172	172	3.75
	Rectal	36.5	36.5	36.8	37.0	37.1	37.2	37.4	37.5	37.5	37.7	
R.S.	Pulse	108	124	140	144	148	164	164	164	168	164	4.00
	Rectal	36.6	36.7	36.9	37.0	37.1	37.2	37.3	37.4	37.5	37.6	
		<u>110 Degrees</u>										
L.G.	Pulse	128	140	140	148	140	160	172	176	180	--	12.00
	Rectal	36.9	37.0	37.1	37.3	37.5	37.6	37.7	38.0	38.1	--	
R.G.	Pulse	116	124	136	144	148	156	164	172	176	180	15.50
	Rectal	36.6	36.7	36.9	37.0	37.0	37.2	37.3	37.5	37.5	37.6	
D.H.	Pulse	140	152	156	160	164	172	172	180	--	--	19.00
	Rectal	36.9	37.0	37.1	37.2	37.4	37.5	37.7	38.0	--	--	
R.S.	Pulse	120	136	140	148	160	164	172	180	--	--	12.50
	Rectal	36.8	36.9	37.0	37.1	37.2	37.4	37.6	37.8	--	--	

APPENDIX B (Continued)

		<u>110 Plus Radiant</u>										
		Intervals										
Subject		5	10	15	20	25	30	35	40	45	50	Recovery in Minutes
L.G.	Pulse	116	140	152	160	160	172	172	180	--	--	10.75
	Rectal	36.8	36.9	37.0	37.1	37.3	37.5	37.6	37.7	--	--	
R.G.	Pulse	120	144	144	148	172	176	188	--	--	--	9.75
	Rectal	36.6	36.6	36.7	--*	--*	--*	--*	--	--	--	
D.H.	Pulse	124	140	144	152	164	168	172	184	--	--	14.75
	Rectal	37.0	37.0	37.1	37.2	37.3	37.4	37.6	37.8	--	--	
R.S.	Pulse	120	136	152	152	160	164	176	188	--	--	19.50
	Rectal	36.7	36.8	36.9	37.0	37.2	37.5	37.7	37.9	--	--	

*Rectal probe malfunction.